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OPTIMIZATION OF DESIGN PARAMETERS OF BELLOWS EXPANSION JOINTS

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ABSTRACT

A technique for optimizing the design parameters of the metal corrugated shell of bellows expansion joints is proposed. The purpose of the development is to improve the accuracy of resource assignment, as well as further design of bellows expansion joints with increased low-cycle and high-cycle fatigue strength. The methodology combines traditional design work and the use of the software package of the Unified Computer System "Gradient". The package contains a procedure for verifying the limitations of the formula for calculating the surface area of the corrugation, its volume and corrugation sweep. The algorithm for calculating the longevity of the compensator consists of two parts: the first one contains the calculation of the compensator for fatigue with axial and transverse displacements without taking into account the internal pressure, the second one - the calculation of the compensator for fatigue taking into account the increased internal pressure. The durability of the compensator is determined by the magnitude of the voltage swing. The package allows the calculation of voltage parameters for single-layer and multi-layer (two-layer) corrugated shells, depending on the movements and internal pressure. Analysis of the stress state under given operating conditions is the basis for optimizing the design parameters of bellows expansion joints. The first contains the calculation of the compensator for fatigue in axial and transverse movements; the second is the calculation of the compensator for fatigue under pressure. The durability of the compensator is determined by the magnitude of the intensity of the voltage. The package allows you to calculate the parameters of the upper and lower shells, the voltage in the compensator corrugations for the upper and lower shells from displacements and internal pressure.

KEYWORDS* : *Bellows Compensator, Optimization & Geometric Parameters

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INTRODUCTION

At present, bellows expansion joints are widely used in various fields of engineering, in particular, in machine building, aviation, instrument making. The main elements of the design of bellows are corrugated metal shell and sheath [6-9].

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There is a need for an accurate designation of the resource of bellows expansion joints at the design stage, which will eliminate their destruction during operation.

A feature of the bellows expansion joints is the presence of vibrations, which leads to fatigue failure. The element responsible for the compensator's resource is the corrugated shell (GO). The stress-strain state of a corrugated shell is directly related to its design parameters [3-10]. Thus, the question of optimizing the design

parameters of bellows expansion joints is topical.

MATERIALS AND METHODS

The lack of reliable methods for predicting the vibration resistance of compensators compels numerous tests in a wide range of frequencies, different levels of disturbing forces, pressures and flow velocities, and working media during the debugging stage [3-10]. This approach is ineffective.

The software package of the "Gradient" was designed to calculate and optimize the design parameters of the corrugated shells of compensators, to determine the optimum tolerances for geometric parameters of the corrugation.

We assume that the profile of the corrugation of the compensator is approximated by two torus shells (external and internal) connected by rectilinear plates [16-18]. Its geometry is determined by the following geometric parameters (Figure 1): D_y – conditional, internal diameter of the compensator; h – corrugation height; t – the profile step; R_1 – the radius of the vertex (outer); R – the radius of the cavity (internal); S – the wall thickness; η – the number of wall corrugations.

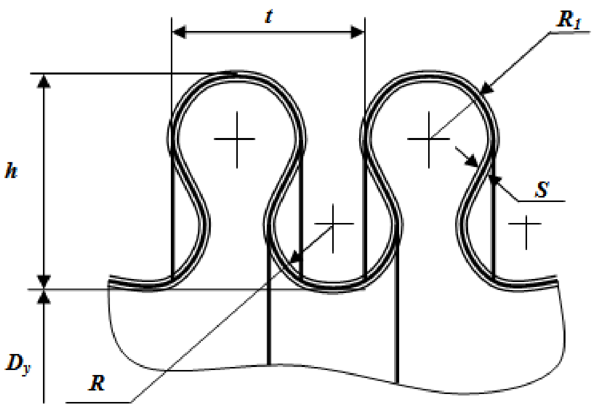

Figure 1: The Geometric Characteristics of the Corrugated Shell

The package contains a procedure for verifying the limitations of the formula for calculating the surface area of the corrugation, its volume and corrugation sweep.

The algorithm for calculating the longevity of the compensator consists of two parts: the first contains the calculation of the compensator for fatigue in axial and transverse movements; the second is the calculation of the compensator for fatigue under pressure. The longevity of the compensator is determined by the value of the stress intensityσ_i. The package allows calculating the parameters of the upper and lower shells, the voltage in the compensator corrugations for the upper and lower shells from displacements and internal pressure.

Guarantee longevity compensators (N_r) is determined by the formula

$$N_r = \frac{N_{0,5}}{n_n}$$

Where, $N_{0,5}$– average number of cycles to failure;n_n – margin of safety in cycles depending on the probability of non-destruction.

When calculating the design, the sheath stresses in the elastic region are determined. This makes it possible to

calculate the pressure at which the plastic deformation of the corrugations begins P_{def} [13, 14]:

$$P_{def} = \frac{[\sigma]}{\sigma_{i/P=1}}$$

Where, $[\sigma]$ – conditional tolerances;$\sigma_{i/P=1}$ – the stress in the corrugated shell from the internal pressure at $P = 1$.

Working pressure of the compensator P_{op} is determined by the formula [11,12]:

$$P_{op} = \frac{P_{def}}{n_p}$$

Where, P_{op} is the pressure at which the plastic deformation of the corrugations begins;n_p– the safety factor for pressure;

$$n_p = 1{,}25 \div 1{,}5$$

When designing compensators and their development, it is necessary to estimate with sufficient accuracy the magnitude of the critical pressure. Therefore, a formula is introduced in the package for the calculation of the critical pressure, which is usually calculated by Euler's formula [1, 19-21]:

$$P_{cr} = \frac{\pi^2 (EI)_0}{F(\nu l)^2}$$

Where,$(EI)_0$– bending stiffness of the shell; F– effective area of the compensator; ν– coefficient of reduction of length; l– the length of the corrugated part.

It is possible to model the corrugated shell (CS) resource depending on various parameters based on the statistical modeling and planning of the experiment. Using the Monte Carlo procedure [2, 22, 23], it is possible to obtain the resource variance$(\Delta N = N_{max} - N_{min})$depending on the geometric parameters of the corrugation and the physical and mechanical characteristics of the material, to estimate the effect on the dispersion of each parameter, and to search for the optimum corrugation profile.

The optimum profile will be considered a corrugation profile, in which the compensator satisfies the required tactical and technical requirements for displacement, working pressure, temperature, is operable for a specified number of cycles and has the lowest mass.

The optimization problem under consideration is formulated as follows:

To find:

$$G_{min} = \gamma V \tag{1}$$

on condition

$$N \geq n_n N_n \tag{2}$$

WhereG_{min} – the mass of corrugated shell; γ is the density of the corrugated shell material; $V$is the volume of the CS material; n_n - margin of safety; $N$is the number of cycles before failure; N_n- assigned (required) resource in cycles.

The volume of the CS material can be represented as the following analytical dependence [15]:

$$V = \pi\left(D_y S + S^2\right)\eta \tag{3}$$

Where l_r – the length of the bellows part of the bellows compensator is determined [3, 15]:

$$l_{\mathrm{r}} = (R + R_1)\left\{\pi + \left[arccos\frac{t}{2\sqrt{\left(\frac{t}{2}\right)^2 - (h-R-R_1-S)^2}} - arccos\frac{(R+R_1)}{\sqrt{\left(\frac{t}{2}\right)^2 - (h-R-R_1-S)^2}}\right] + 2\sqrt{\left(\frac{t}{2}\right)^2 + (h-R-R_1-S)^2 + R + R_1}\right\} \quad (4)$$

The algorithm for determining the spread of the resource and optimizing the profile is as follows.

The following initial data are specified: displacement, pressure, number of layers of CS, thickness and physical, mechanical characteristics of the material, safety factor, and assigned resources.

The intervals for changing the number of corrugations and the geometric parameters of the profile are specified:

$$\eta^{(1)} \le \eta \le \eta^{(2)}$$

$$h^{(1)} \le h \le h^{(2)}$$

$$t^{(1)} \le t \le t^{(2)} \quad (5)$$

$$R^{(1)} \le R \le R^{(2)}$$

$$R_1^{(1)} \le R_1 \le R_1^{(2)}$$

The points from the given intervals are chosen randomly.

The boundary conditions are checked. If the boundary conditions are not satisfied, proceed to step 3. Otherwise, the calculation is repeated.

The values N, V, P_{def}, P_{cr} are remembered (typed) if the following conditions are fulfilled:

$$P_{def} \ge 1{,}7\ P_{op}$$

$$P_{cr} \ge 1{,}7\ P_{op}$$

Otherwise, go to step 3.

To determine the magnitude of the scatter among the selected points, points that have $N_{max}$and $N_{max}$are found and are calculated

$$\Delta N = N_{max} - N_{min}$$

Points that satisfy conditions (1) and (2) are considered optimal

The presence of a significant resource variance($\Delta N = N_{max} - N_{min}$)will make it necessary to select large safety reserves ($n_n = 3 \ldots 15$) to ensure the operation of the CS with a given reliability (guaranteed resource, assigned resource). Therefore, it is important to reduce the spread of the resource, as this will reduce the safety margin, approaching the assigned number.

Regression dependences were obtained on the basis of simulation modeling for the analysis of the effect on the magnitude of the dispersion of physical and mechanical characteristics, the thickness of the material, and the tolerances on geometric parameters. Analysis showed that in the overall spread of the resource, the share of the spread due to deviations of geometric parameters within tolerances is on average 28 %. 72% of the spread are due to the dispersion of material properties within tolerances (tape made of steel 12H18N10T GOST 5581-61), 25% of them take into account the

dependence on the thickness of the material.

Tighter tolerances on geometric parameters of corrugations in relation to existing in 2; 3; 4 times will increase the resource, respectively, in 1.6; 2.0; 2.1 times.

Technological tolerances for the height of the corrugation h, step t, outer and inner radiiR_1, R, length l_r are currently assigned. The tolerance for the total thickness (of all layers) of CS is not established. However, analysis shows that the thickness of the material is one of the most significant factors affecting the spread of the resource.

The methods and programs on the computer were developed to determine the optimum tolerances for the geometric parameters of the corrugation. These programs can determine the tolerance for the thickness of the material, as well as allowance for tolerances on the properties of the tape material.

The mass and resource of CS are chosen as criteria for determining the tolerances. To find a solution that simultaneously satisfies the extreme values of both criteria is impossible, so the solution must be sought on the basis of a compromise between them.

The nominal profile of the corrugation and the number of corrugations are chosen from the condition for minimizing the mass of the CS when performing the specified tactical and technical characteristics and condition (2).

Let it h_0, t_0, R_{10}, R_0, η_0, S_0 – optimal (nominal) values of geometrical parameters of corrugated metal shells; $\delta h, \delta t, \delta R_1, \delta R, \delta S$ – the tolerances for h, t, R_1, R, S.

The values $\delta h, \delta t, \delta R_1, \delta R, \delta S$ can be either positive or negative.

The problem of constructing the area of compromise is formulated as follows:

Find G_{min} (G_{max})under the condition

$N \geq n_{n+1} N_n$

Here$n_{n+1} = n_n - \Delta n_n$, where$\Delta n_n$ – strength margin, $G$is determined by the formulas 1, 3, 4.

Two approaches are used to determine the dependence of the number of cycles on the geometric parameters of the corrugation. In the first approach, the algorithm for calculating the tolerances is as follows:

Select a tolerance system, that is, a constraint system

$$h^{(1)} \leq h \leq h^{(2)} - h^{(0)}$$

$$t^{(1)} \leq t \leq t^{(2)} \tag{6}$$

$$R^{(1)} \leq R \leq R^{(2)}$$

$$R_1^{(1)} \leq R_1 \leq R_1^{(2)}$$

Based on the Monte Carlo procedure and the methodology of [1], the range of values of V and $N$is constructed and is determined byV_{max}andN_{min}.

Calculate the values of the concessions:

$$\Delta V = V_{max} - V^0$$

$\Delta N = N^0 - N_{min}$

If the accepted values of the concessions are accepted, the process ends, if not, the following tolerance values are selected using the gradient method.

In the second approach, the algorithm for calculating the tolerances is as follows: based on mathematical modeling, a regression dependence of the resource on the geometric parameters of the corrugation is constructed in a region broader than the assumed spread of the geometric parameters.

A system of constraints is chosen by formula (6).

The following tolerances are found using the "Gradient" computer and the regression dependence obtained:

$$\delta h = h^0 - h$$

$$\delta t = t^{(2)} - t \tag{7}$$

$$\delta R_1 = R_1^{(2)} - R_1$$

$$\delta R = R^{(2)} - R$$

V_{max} and N_{min}

V_{max} and N_{min} are determined.

The values of the concessions are calculated

$$\Delta V = V_{max} - V^0 \tag{8}$$

$$\Delta N = N^0 - N_{min} \tag{9}$$

If the values of the concessions obtained are satisfied for this tolerance system, then the calculation ends. Otherwise, the following constraint values are continued.

RESULTS AND DISCUSSIONS

The result of the work was the creation of prototypes of corrugated shells using the developed program "Gradient". Samples were subjected to traditional tests. The test results showed that the resource of samples designed using the Gradient program was higher than the samples of the control group by an average of 5% when using the first approach to calculation and an average of 3.5% when using the second approach.

Depending on the requirements for the degree of reliability of the design, one of the two described approaches to the calculation can be used.

The second approach saves computer time, but it is less accurate.

CONCLUSIONS

The proposed technique significantly reduces the time for fine-tuning and optimizing the design parameters of bellows expansion joints [24, 25]. Allows you to more accurately assign operational resource, eliminates the need for a large number of tests.

The software package of the EU computer "Gradient" is applicable for various operating conditions and can be

used to calculate the bellows expansion joints of various design parameters.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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